MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EEL1206 – INTRODUCTION TO MACHINES AND POWER SYSTEMS

(EE, CE, MCE, ME, TE, OPE, NT)

29 FEBRUARY 2020
2.30 p.m - 4.30 p.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of **7** pages including the cover page and Appendix. There are **FOUR** questions in this paper.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of marks for each question is given.

3. Some useful formulae are given in the Appendix section.

4. Please write all your answers in the Answer Booklet provided.

Question 1

(a) Figure Q1 shows a ferromagnetic core structure with current i = 2.5A flowing through a 800-turn coil wrapped around the left side of the core. The depth of the core is 8cm, and the other dimensions of the core are indicated in the diagram. The core has a relative permeability of 1400. Due to the fringing effect, the effective area of the air gap is 10% larger than the physical core area.

(i) Find the total reluctance of the core structure. [5 marks]

(ii) Determine the flux density at the top of the core. [4 marks]

(iii) Calculate the magnetic field intensity of the air gap. [3 marks]

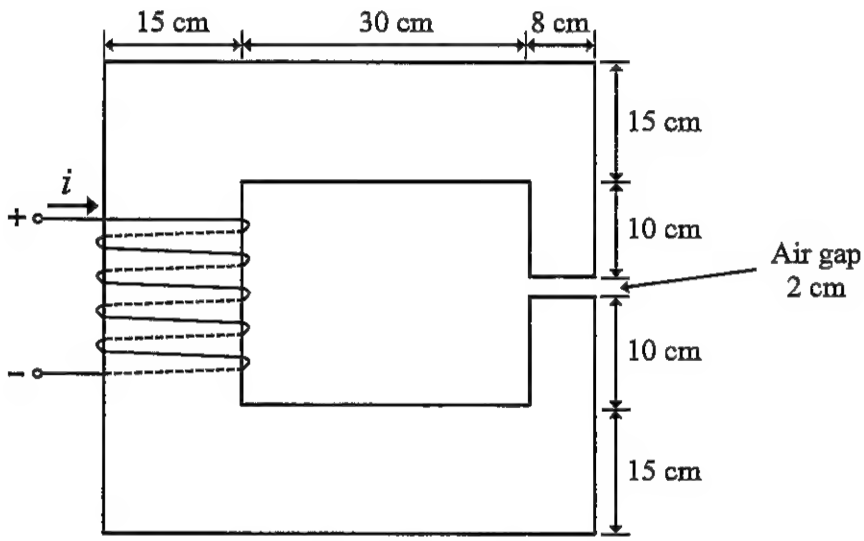


Figure Q1

(b) A balanced three-phase power system consists of an ideal Y-connected generator having a phase voltage of 440 V and a positive phase sequence. The generator is connected through a three-phase transmission line to a Y-connected load. The transmission line has an impedance of $(1 + j0.5)$ Ω per phase, and the load has an impedance of $(30 + j40)$ Ω per phase.

(i) Sketch the per-phase equivalent circuit of the system. [2.5 marks]

(ii) Find the line currents $\mathbf{I}_a$, $\mathbf{I}_b$, and $\mathbf{I}_c$. [4 marks]

(iii) Calculate the total real, reactive, and apparent powers consumed by the Y-connected load. [4.5 marks]

(iv) Determine the generator's power factor. [2 marks]

Continued...

Question 2

(a) Briefly describe the **FOUR** main losses that occur in real transformers, and how they are represented in the transformer equivalent circuit.

[8 marks]

(b) Given the primary and secondary windings of 400 and 250 turns respectively, primary voltage of 208V and primary current of 2A, determine the secondary voltage and current of the transformer.

[4 marks]

(c) The open- and short-circuit tests performed on a 15kVA, 2300/230V transformer gives the following observations:

Open-circuit test (performed on low voltage side)	Short-circuit test (performed on high voltage side)
$V_{oc} = 230V$	$V_{sc} = 47V$
$I_{oc} = 2.1A$	$I_{sc} = 6.0A$
$P_{oc} = 50W$	$P_{sc} = 160W$

(i) Determine the impedances R_{eq}, X_{eq}, R_c and X_m of the transformer.

[7 marks]

(ii) Sketch the approximate equivalent circuit referred to the primary side.

[3 marks]

(d) Briefly describe autotransformers, and what they are mainly used for.

[3 marks]

Question 3

(a) A **shunt DC generator** has the following data:

Rated power $P_o = 8kW$,
Rated terminal voltage $V_T = 160V$,
Armature resistance $R_A = 0.2\Omega$,
Shunt field resistance $R_F = 40\Omega$

(i) Draw the equivalent circuit of the generator.

[2 marks]

(ii) Calculate the induced voltage E_A at rated load. Assume there is a brush contact drop of about 2V.

[3 marks]

Continued...

(b) Figure Q3 shows the power flow of **induction motors.**

(i) Express the equations for the air-gap power P_{AG}, converted power P_{conv}, and output power P_{out} in terms of the synchronous speed ω_{sync}, motor speed ω_m, induced torque τ_{ind} and/or load torque τ_{load}.

[3 marks]

(ii) From the equations, derive the relations between P_{AG} and P_{conv}.

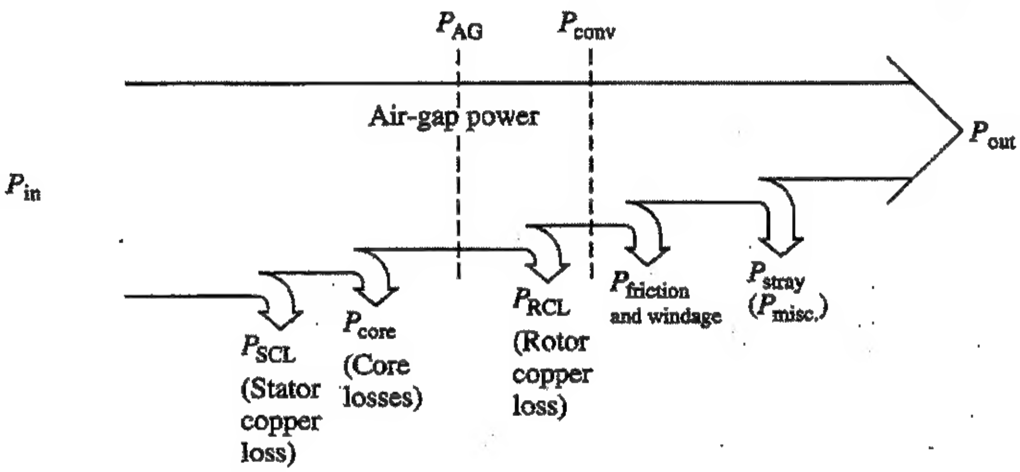
[2 marks]

(iii) Express the rotor copper loss P_{RCL} in terms of P_{AG}.

[2 marks]

(iv) Given $P_{AG} = 1500W$ and $P_{conv} = 1200W$, determine the slip of the induction motor.

[2 marks]



FigureQ3

(c) Briefly describe the stator and rotor constructions of a **synchronous generator.** Explain the difference between the salient and the non-salient pole rotor characteristics.

[6 marks]

(d) A 3-phase Y-Connected **synchronous generator** with a rated field current of 60A was tested and the following data was taken:

- DC Test → $V_{DC} = 15V, I_{DC} = 25A$
- Open-circuit test → $V_{OC} = 6928V$ at rated field current
- Short-circuit test → $I_{SC} = 1000A$ at rated field current

Determine the armature resistance R_a and synchronous reactance X_S of the equivalent circuit.

[5 marks]

Continued...

Question 4

(a) Figure Q4(a) illustrates the one-line diagram of an electrical power system. The ratings of the various components in the power system are given as follows:

Generator, G1:	150 MVA, 28 kV, $R = 5$ %, $X = 90$ %
Generator, G2:	300 MVA, 28 kV, $R = 10$ %, $X = 90$ %
Transformer, T1:	100 MVA, 28/240 kV, $R = 2$ %, $X = 10$ %
Transformer, T2:	80 MVA, 280/18 kV, $R = 2$ %, $X = 10$ %
Motor, M:	75 MVA, 12 kV, $R = 15$ %, $X = 85$ %

The transmission line has an impedance of $(10 + j45)\Omega$, and the static load impedance is $(2.5 + j2.8)\Omega$. Consider a base apparent power of 150 MVA and a base voltage of 28kV at the generator side.

(i) Determine the base voltages and impedances in Regions 1, 2 and 3. [5 marks]

(ii) Draw the impedance diagram of this power system, and clearly indicating all the impedances and their values in per-unit (p.u.) quantities. [8 marks]

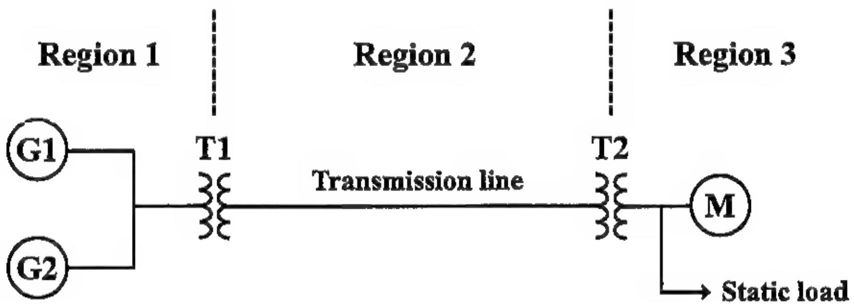


Figure Q4(a)

(b) A simple protection scheme can be constructed from five basic components, which include the current transformer, protective relay, tripping coil, auxiliary DC source, and circuit breaker.

(i) Name **TWO** basic requirements of protective devices. [2 marks]

(ii) With the aid of a suitable diagram, explain how a protection scheme protects an electrical power system from a fault in the transmission line. [5 marks]

Continued...

(c) An Inverse Definite Minimum Time (IDMT) overcurrent relay is used to protect a distribution feeder. The time-delay characteristic of the relay is as shown in Figure Q4(c). The relay is connected to a 400:5 current transformer and a circuit breaker, and is set to operate when the load current on the feeder exceeds 800A. For a chosen time-dial setting of 9, determine the operating time of the relay for a fault current of 3200A. [5 marks]

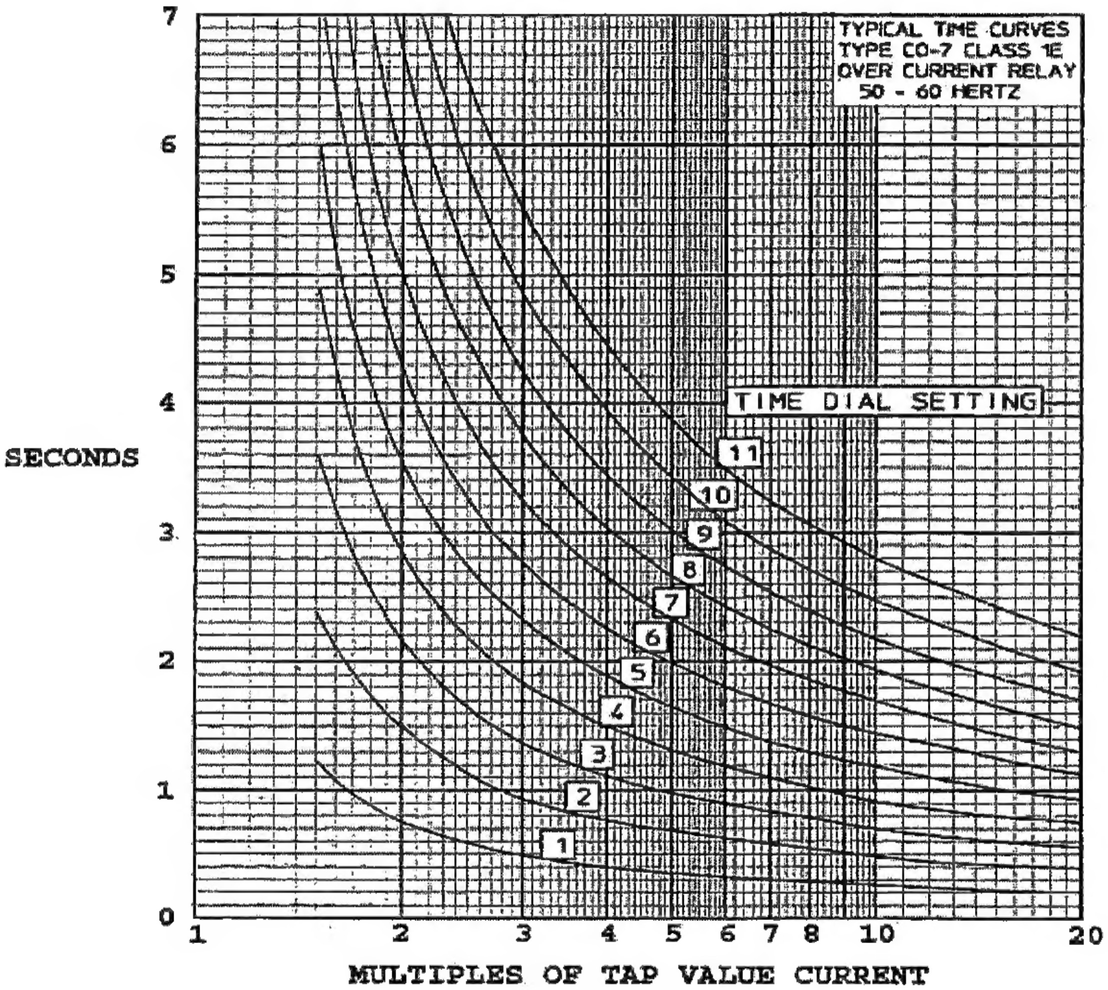


Figure Q4(c)

End of Questions

APPENDIX

Magnetic Circuits

$$H = \frac{Ni}{l_c}$$

$$B = \mu H = \mu_0 \mu_r H$$

$$\phi = BA$$

$$\mathfrak{R} = \frac{l_c}{\mu A}$$

$$\mathcal{F} = Ni = \phi \mathfrak{R} = Hl_c$$

$$\mathcal{F} = ilB \sin\theta$$

$$e_{ind} = vlB \sin\theta_1 \cos\theta_2$$

$$P = \tau\omega$$

Three-Phase Circuits

Y-Connection: $I_L = I_\phi$, $V_L = \sqrt{3}V_\phi \angle 30°$

Δ-Connection: $V_L = V_\phi$, $I_L = \sqrt{3}I_\phi \angle -30°$

Δ-Y Transformations:

$$R_a = \frac{R_{ac}R_{ab}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_b = \frac{R_{ab}R_{bc}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_c = \frac{R_{bc}R_{ac}}{R_{ac} + R_{ab} + R_{bc}}$$

Y-Δ Transformations:

$$R_{ac} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_b}$$

$$R_{ab} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_c}$$

$$R_{bc} = \frac{R_aR_b + R_bR_c + R_cR_a}{R_a}$$

$$P_T = 3|V_\phi||I_\phi|\cos\theta = \sqrt{3}|V_L||I_L|\cos\theta$$

$$Q_T = 3|V_\phi||I_\phi|\sin\theta = \sqrt{3}|V_L||I_L|\sin\theta$$

$$S_T = 3|V_\phi||I_\phi| = \sqrt{3}|V_L||I_L|$$

Transformers

Turn ratio: $a = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$

Equivalent circuit (referred to primary):

$V_s' = aV_S$, $\quad I_s' = \frac{I_S}{a}$

$R_s' = a^2R_S$, $\quad X_s' = a^2X_S$, $\quad Z_L' = a^2Z_L$

$R_{eqP} = R_P + a^2R_S$, $\quad X_{eqP} = X_P + a^2X_S$

Equivalent circuit (referred to secondary):

$V_P' = \frac{V_P}{a}$, $\quad I_P' = aI_P$

$R_P' = \frac{R_P}{a^2}$, $\quad X_P' = \frac{X_P}{a^2}$

$R_{eqS} = R_S + \frac{R_P}{a^2}$, $\quad X_{eqS} = X_S + \frac{X_P}{a^2}$

Short-Circuit Test

$Z_{eq} = \frac{V_{SC}}{I_{SC}}$, $\quad R_{eq} = \frac{P_{SC}}{I_{SC}^2}$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$$

Open-Circuit Test

$R_C = \frac{V_{OC}^2}{P_{OC}}$, $\quad S_{OC} = V_{OC}I_{OC}$

$$Q_m = \sqrt{S_{OC}^2 - P_{OC}^2}$$

$$X_m = \frac{V_{OC}^2}{Q_m}$$

Voltage Regulation

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

Efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

End of Paper